Measured responses to quantum Bayesianism

David Mermin, in his commentary in the July 2012 issue of PHYSICS TODAY (page 8), put forth what he calls the QBist (quantum Bayesian) approach to quantum foundations. He claims that replacing a frequentist approach to quantum probabilities with a Bayesian approach solves the quantum measurement problem and fixes the "shifty split" between classical and quantum that John Bell complained about.[1] I disagree. Mermin has not addressed the real issue that besets quantum probabilities, he has not solved the measurement problem, and he has put the shifty split in the wrong place.

The quantum measurement problem, understanding an actual physical measurement in fully quantum terms, has two parts. First, unitary time development (Schrödinger's equation) often results in a quantum superposition of different outcomes—different positions of the apparatus pointer, in the quaint language of quantum foundations. Various equivocations proposed to get rid of that Schrödinger's cat were among the main targets of Bell's critique. When this first part is solved the second task is to link the pointer position to the microscopic property the apparatus was designed to measure, at a time *before* the measurement took place. Experimental physicists talk about detecting a gamma ray emitted by a nucleus, or a neutrino emitted in a supernova explosion, using apparatus that either destroys or violently alters the object under study. They are not fools, though one might think so from reading textbook discussions of measurement that only consider properties of a microscopic system at a time after interacting with the apparatus—best referred to as a preparation, not a measurement.

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Mermin seems to think that the measurement problem—presumably the first problem—is solved by using the quantum wavefunction to calculate a probability, in a manner easily taught to undergraduates. However, the main conceptual difficulty with quantum probabilities is not in calculating them but in identifying their referents, what it is they are about. When the weatherman assigns a high probability to a severe thunderstorm on Thursday afternoon, both frequentists and Bayesians will want to seek shelter. They will agree that the probability refers to thunderstorms rather than stock-market prices. The first task in constructing a probabilistic model, for the weather or games of chance or radioactive decay, is to identify a sample space of mutually exclusive possibilities, one and only one of which can be correct or occur in a particular experiment or on a particular occasion. Only when a sample space has been defined is it possible to assign probabilities to suitable subsets, averages to random variables, and so forth.

A classical phase space is easily turned into a probabilistic sample space: The different points represent distinct physical states of affairs. But a quantum Hilbert space is very different if, following John von Neumann's thinking, one associates physical properties with (closed) subspaces and associates their negations with orthogonal complements of the subspaces. That classical–quantum difference was the origin of quantum logic,[2] which, despite early hopes and much hard work, has not resolved the conceptual difficulties of quantum mechanics.[3] But it does point to important issues that need to be considered when discussing quantum probabilities. Mermin and his fellow QBists should pay attention.

Quantum orthodoxy has no solution for the fundamental problem of defining a quantum sample space. Instead, it covers with a black box the mysterious whatever-it-is that the quantum wavefunction might have something to do with. Talking about what is under the box is more or less strictly forbidden, for it is well known that physicists who attempt to do so will fall into the quantum swamp, to be eaten by the Great Smoky Dragon or driven insane by the Paradoxes. The black box is my term for Bell's split between the macroscopic and microscopic, a split forever shifting as experimentalists manage to entangle larger and larger quantum systems. According to Mermin, the QBists place the split "between the world in which an agent lives and her experience of that world." That is no improvement: The box would then cover the physicist rather than the quantum mystery. Bell would not have been pleased.

Bell was unaware of the consistent or decoherent histories approach to quantum mechanics,[4] which, unlike QBism, solves both measurement problems in a way fully consistent with the Hilbert space structure of quantum mechanics and consistent with special relativity. It drives the shifty split off to infinity where it belongs: Quantum physics applies at all scales, from the quarks to the quasars. And it gets rid of the spooky nonlocal influences that Einstein found so distasteful. It seems odd that Mermin has thrown his lot in with the QBists rather than paying serious attention to the histories approach which, unlike QBism, clearly satisfies two desiderata for a good quantum interpretation that he himself put forward 15 years ago:[5] "The theory should describe an objective reality independent of observers and their knowledge" and "objectively real internal properties of an isolated individual system should not change when something is done to another non-interacting system."

Mermin says even undergraduates can be taught enough quantum mechanics to update a quantum state assignment. I remember when my undergraduate quantum mechanics teacher, Robert Dicke of cosmic-background fame, was visibly uncomfortable as he introduced us to wavefunction collapse. For those who share this discomfort, I recommend that rather than telling students to "shut up and calculate," we

▶ Introduce them to the rudiments of probability theory, including the conditional probabilities used by both frequentists and Bayesians; one need not take sides.

▶ Explain how to construct quantum sample spaces and assign probabilities in a way that does not generate paradoxes.

▶ Explain wavefunction collapse as a tool for calculating certain conditional probabilities that can also be obtained using other methods; it is not a physical process.

Readers who want more details can contact me or consult the works cited in reference 4. I think it is high time we abolished antiquated approaches to teaching quantum theory along with the shifty split that confuses both students and their instructors.

References

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3. G. Bacciagaluppi, in *Handbook of Quantum Logic and Quantum Structures: Quantum Logic*, K. Engesser, D. M. Gabbay, D. Lehmann, eds., North-Holland, Amsterdam (2009), p. 49.
4. P. C. Hohenberg, *Rev. Mod. Phys.* **82**, 2835 (2010); R. B. Griffiths, *Consistent Quantum Theory*, Cambridge U. Press, New York (2002); R. B. Griffiths, *Found. Phys.* **41**, 705 (2011).
5. N. D. Mermin, *Pramana* **51**, 549 (1998).

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■ **David Mermin's exposition** on QBism was excellent. However, it left the reconciliation between subjective and objective probability up in the air. There must be circumstances in which the subjective probabilities of different scientifically trained agents coincide, and hence the subjective and objective approaches also coincide. Quantum mechanics reminds us, if such a reminder is needed, that the human experiences that produce coinciding subjective probabilities, and hence interesting science, form a small subset of all human experiences.

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■ **Some time ago,** John Bell and I wrote a tongue-in-cheek article on the interpretation of quantum mechanics;[1] in it we remarked that only a minority of physicists had any interest in the topic and that the typical physicist thought he would understand it "if ever he can spare twenty minutes to think about it." According to David Mermin, however, that situation has changed dramatically, and "new interpretations [of quantum mechanics] appear every year."

Actually, most textbooks on the subject continue to be based on the well-established Born interpretation of quantum mechanics, which postulates that the absolute square of the Schrödinger wavefunction, projected onto a particular quantum state, gives the